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The recent uvigerinids (benthic foraminifera) in the northeastern Gulf of Cadiz

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ABSTRACT

The distributional patterns and related environmental parameters for nine *Uvigerina* (benthic foraminifera) species occurring in the northeast Gulf of Cadiz are discussed. A new species (*Uvigerina pusilla* n. sp.) is described. Two assemblages (F1: *Uvigerina peregrina* and F2: *Rectuvigerina phlegeri*) are characteristic of the distribution of uvigerinids in this region, related to bathymetry and the mud-sand substrate in North Atlantic Superficial and Central water.

Key words: Foraminifera, uvigerinids, *Uvigerina pusilla* n. sp., Gulf of Cadiz, Spain.

RESUMEN

Uvigerínidos (foraminíferos bentónicos) recientes en el noreste del golfo de Cádiz

*Se ha determinado el área de distribución de los uvigerínidos (foraminíferos bentónicos) en el noreste del golfo de Cádiz, donde se han encontrado nueve especies. Su distribución está relacionada con las características texturales y geoquímicas del sedimento. Se ha descrito una especie nueva (*Uvigerina pusilla *nov. es.). Mediante análisis factorial y regresión multilineal se han diferenciado dos asociaciones, F1 (*Uvigerina peregrina*) y F2 (*Rectuvigerina phlegeri*) relacionadas con las características batimétricas y geoquímicas del medio, en la zona de influencia del agua superficial y central noratlántica.*

***Palabras clave**: Foraminíferos, uvigerínidos,* Uvigerina pusilla *nov. es., golfo de Cádiz, España.*

INTRODUCTION

Uvigerina constitute an important group of benthic foraminifera: they are widespread, cover a wide range of environments, and are potentially of great value for palaeoecological reconstructions. Over the past several decades much research has been done on Uvigerina taxonomy, and their use as (palaeo-)environmental index species has been pointed out in a considerable number of studies (e.g. Seiglie, 1968; Lutze and Coulbourn, 1984; Van der Zwaan *et al.*, 1986). The distribution patterns of some uvigerinids are also used for the mapping of large-scale watermass movements during glacial-interglacial times (Schnitker, 1979). In spite of all these research efforts, we know relatively little about the palaeoecology and palaeobiogeography of the uvigerinids; a major drawback in this regard is the confusion in the taxonomy of these benthic foraminifera.

The present study is a part of an unpublished doctoral thesis (Villanueva Guimerans, 1994) and its main objectives are to review the available taxonomic information and describe the distribution pattern of the uvigerinids found in the surface sediments from the continental margin of the Gulf of Cadiz. The benthic foraminifera on the Iberian coast have been studied by different authors, mainly on the Spanish littoral (Mateu, 1970; Sánchez-Ariza, 1979; Pascual Cuevas, 1984; Cearreta, 1989; for a summary, see Colom, 1974); other have reported on the Portuguese coast (Levi *et al.*, 1995; Schöenfeld, 1997).

General Setting

The study zone located on the continental shelf of northern Gulf of Cadiz, between the mouth of the Guadalquivir River (36° 50' N) and Cape of Trafalgar (36° 10' N), in southwest Spain (figure 1a). Its hydrodynamics are affected by the coastal orientation with a linear trend north-northwest-south-southeast several steps east-west, by the littoral currents and by the exchange of water masses between the Atlantic and Mediterranean through the Straits of Gibraltar. In this area there is North Atlantic Surface Water to a depth of approximately 140 m, with clear seasonal variation at a deeper level; some North Atlantic Central Water has been detected, as well as the presence of outflow Mediterranean Water below 500 m (figure 1c) (Melières, 1974). Recent nonconsolidated sediments in this area are siliciclastic, with quartz as the most abundant mineral in the sandy sediments. In the infralittoral domain, fluvial-deltic depositional processes prevail in the northern sector in relation to the Guadalquivir River's mouth; moreover, in the central and southern sector infralittoral depositional processes prevail, as well as the development of discontinuous sand-wave fields. In front of Cadiz Bay the depositional processes of sediment input of the inner bay and the erosional processes due to strong tidal steam co-exist. On the continental shelf domain there is a northern sector, where the fluvio-deltaic depositional processes related to the

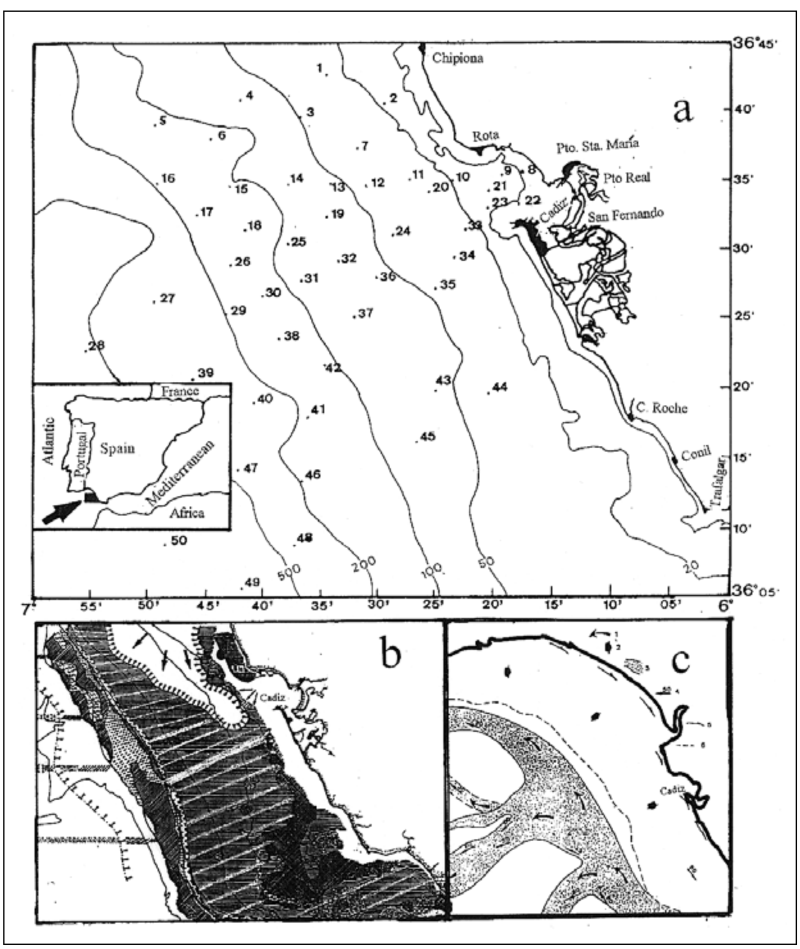

Figure 1. (a): Geographical, bathymetric and situation of the samples in the Gulf of Cadiz. (b): Morphological features (Lobo *et al.* 1997). (c): Hydrodynamic circulation model (Melières, 1974)

Guadalquivir River input prevail, determining a sedimentary dynamics towards the southeast; a central sector, with the presence of large sand bodies over a shallow abrasion shelf at a depth of 25-30 m; and a southern sector, where the fluvio-deltaic depositional processes related to the Barbate river input co-exists with erosive processes due to the interactions of the water flow towards the north-northwest. On the shelf-break, the progradational depositional processes prevail in the north and central sector, and the neotectonic and depositional processes in the southern sector. On the upper

Table I. Environmental parameters

ST	Lt(N)	Lg(W)	Clay	Silt	Sand	Grav	Depth	Carb.	Quartz
01	36°-42'	06°-34’	53.9	45.0	00.6	00.5	024	33.4	21.8
23	36°-40’	06°-29’	64.2	45.0	00.4	00.4	021	30.6	21.7
03	36°-40’	06°-36’	51.3	48.0	00.7	00.0	041	28.5	21.7
04	36°-41’	06°-41’	59.4	40.1	00.5	00.0	061	30.9	17.7
05	36°-39’	06°-49’	45.5	27.8	26.4	00.3	115	26.8	34.1
06	36°-38’	06°-44’	66.9	32.5	00.4	00.0	092	26.9	21.7
07	36°-37’	06°-31’	50.5	48.8	00.7	00.0	035	31.1	21.8
08	36°-35’	06°-17’	02.9	10.5	86.6	00.0	012	21.7	49.9
09	36°-35’	06°-19’	44.5	26.6	28.9	00.0	016	27.9	24.7
10	36°-35’	06°-23’	21.3	22.3	54.3	02.1	022	24.9	47.5
11	36°-35’	06°-25’	30.7	25.5	36.1	07.7	030	35.2	38.8
12	36°-35’	06°-31’	68.5	30.2	01.5	00.3	044	26.4	20.5
13	36°-35’	06°-33’	66.5	31.5	01.8	00.2	066	27.0	19.2
14	36°-35’	06°-38’	63.3	35.8	00.5	00.4	074	28.3	21.7
15	36°-34’	06°-44’	25.6	26.8	45.6	02.0	103	30.2	50.1
16	36°-35’	06°-49’	42.3	43.1	14.3	00.3	214	07.6	41.0
17	36°-34’	06°-46’	19.9	21.6	57.8	00.7	126	33.2	49.2
18	36°-32’	06°-40’	56.7	29.0	13.9	00.4	098	18.3	28.1
19	36°-33’	06°-34’	66.3	32.8	00.9	00.0	067	29.1	22.1
20	36°-34’	06°-25’	18.0	11.0	21.5	49.5	032	30.3	58.4
21	36°-34’	06°-21’	75.3	19.0	44.9	00.1	018	28.7	66.9
22	36°-33’	06°-19’	03.2	02.1	94.1	00.6	016	28.6	66.5
23	36°-33’	06°-20’	09.1	08.6	81.7	00.6	020	23.5	79.0
24	36°-31’	06°-29’	65.8	32.3	01.6	00.3	049	29.5	22.3
25	36°-30’	06°-28’	25.9	24.8	47.7	01.6	110	34.4	44.3
26	36°-28’	06°-42’	04.6	09.9	85.5	00.0	147	24.2	61.0
27	36°-26’	06°-49’	13.3	11.0	75.7	00.0	363	36.8	35.7
28	36°-23’	06°-55’	15.4	12.0	72.4	00.0	480	35.7	34.8
29	36°-25’	06°-43’	15.9	24.6	60.3	00.0	243	31.9	50.2
30	36°-27’	06°-39’	03.9	07.7	86.9	01.5	128	25.9	63.1
31	36°-28’	06°-37’	28.6	27.4	42.8	01.2	100	34.6	42.7
32	36°-29’	06°-33’	62.0	28.8	08.8	00.4	073	25.5	25.7
33	36°-31’	06°-22’	18.2	12.5	66.4	02.9	029	25.8	58.0
34	36°-30’	06°-22’	35.4	27.1	32.5	05.0	031	32.1	36.9
35	36°-27’	06°-24’	64.1	32.7	03.2	00.0	047	30.5	22.8
36	36°-29’	06°-30’	64.8	34.1	01.1	00.0	059	26.5	21.9
37	36°-25’	06°-21’	22.8	10.0	64.4	02.8	076	23.9	48.0
38	36°-23’	06°-38’	16.7	11.1	71.5	00.7	168	31.6	55.7
39	36°-21’	06°-45’	11.6	11.6	76.4	00.4	384	31.7	58.1
40	36°-19’	06°-40’	13.2	11.4	75.4	00.0	281	33.7	57.5
41	36°-18’	06°-35’	10.5	07.5	08.5	73.5	160	34.9	59.8
42	36°-23’	06°-32’	12.2	22.4	65.4	00.0	130	24.6	57.5
43	36°-20’	06°-24’	15.5	08.0	73.3	03.2	055	37.0	56.7
44	36°-20’	06°-20’	13.2	03.9	70.6	12.3	045	56.2	55.3
45	36°-16’	06°-25’	04.4	01.2	92.1	02.3	056	50.1	51.6
46	36°-13’	06°-36’	04.1	04.7	91.2	00.0	236	31.1	65.0
47	36°-14’	06°-43’	05.3	06.4	88.3	00.0	560	30.0	64.3
48	36°-08’	06°-37’	03.2	01.5	93.7	01.6	528	32.7	66.0
49	36°-70’	06°-40’	03.8	04.2	92.0	00.0	560	31.1	65.4
50	36°-47’	06°-05’	06.7	05.3	87.0	00.0	610	30.4	65.6

slope, the depositional processes predominate, producing slope aggradation and progradation, gravitational processes, and erosive processes due to the interaction of a Superficial Atlantic Water Flow. On the middle slope, the erosion processes related to interaction with the Mediterranean Outflow prevail, and the combined processes related to the occurrence of trough and submarine canyons (Lobo, 1995; Lobo *et al.*, 1997) (figure 1b).

MATERIALS AND METHODS

The present study is based on selected species of 50 samples (figure 1a) collected using a Shipek bottom sampler. Each sample was washed over a 125-mm sieve, and the residue was split into a fraction containing more than 300 specimens of benthic foraminifera (Buzas, 1990), all of which were sorted and identified. The samples were not stained, so the assemblages could represent both living specimens and empty shells. The foraminifers were well preserved and little affected by dissolution; selected specimens were coated with gold using Blazer sputtering equipment and photographed with a Jeol 820 in the SEM Unit at the University of Cadiz. The grain-size analysis was carried out using the standard sieve-and-pipette method (Folk, 1965); the carbonate content was dtermined using by the Bernard's calcimeter (table I), and organic content with the method of Gaudette *et al.* (1974). The factor and multiple linear regression analyses were carried out using a BMDP statistical program.

RESULTS

Systematic concepts are continually subject to change as more detailed and refined methods of investigation are developed. The species concept applied in the present paper is commonly used for many organism groups: it implies that a species is not defined by a single morphotype, but covers at least the entire range of variation as is found in the association at its type locality (Van der Zwaan, 1982). The classification of Loeblich and Tappan (1988) has been adopted at a suprageneric level and we basically follow Lutze's criteria (1986) for specific determination. The morphological descriptions of the species include the sum of features characterising each species. Particular attention was given to test and chamber shape, pore pattern,

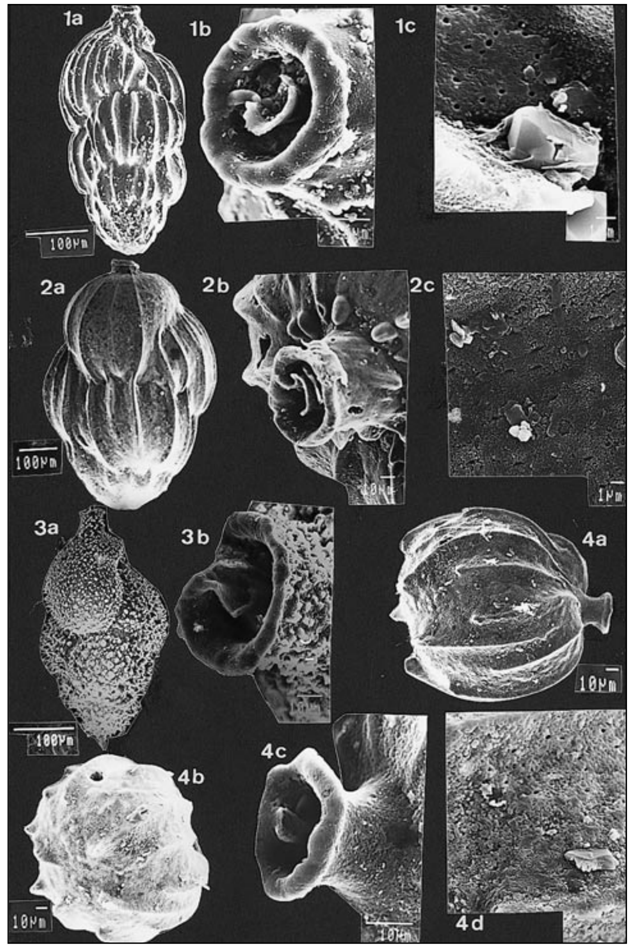

Figure 2. Uvigerinids recovered in the surface sediments. (1a,b,c): *Uvigerina peregrina*; (2a,b,c): *Uvigerina mediterranea*; (3a,b): *Uvigerina auberiana*; (4a,b,c,d): *Uvigerina pusilla* n. sp.

shape and density of costae, presence and frequency of pustules between costae, coiling mode, apertural features, ornamentation and wall texture.

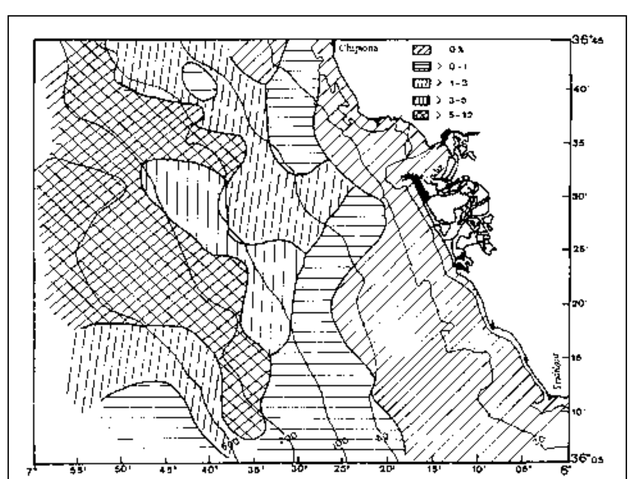

Figure 3. Distribution of *Uvigerina peregrina*

We consider uvigerinids to be member of the Family Uvigerinidae and the genera *Rectuvigerina* (Mathews, 1945) which is placed in the Family Siphogenerinoididae in the Loeblich and Tappan new classification followed in the present study. Both families are grouped in the Superfamily Buliminacea. The qualitative analysis resulted in the identification of nine species, detailed below.

Family Uvigerinidae Haeckel, 1894

Uvigerina peregrina Cushman 1923 (figure 2.1a,b,c)

Test with the chambers low, weakly inflated; surface with longitudinal costae, high and depressed with the upper margin blunt and usually serrate, changing gradually into rows of spines on the later chambers, which are interrupted at sutures, very distinct except in the basal portion; intercostate areas and extremities of test covered with small granules and spines; aperture terminal on a short neck with a coarse lib provided with a internal hemicylindrical toothplate; wall perforated with pores of 0.3-0.6 microns. Dimensions: length, 0.5-0.8 mm; width, 0.2-0.3 mm; neck, 40 microns; aperture, 40 microns. In the study zone (figure 3) it is abundant and widespread except in the infralittoral area, with a correlation coefficient of 0.72 with depth. The percentages of this species show stepwise increasing values: from 20-50 m the frecuency is less than 1 % of the assemblage; up to 100 m, 1-3 %; from 100-200 m, 3-5 %; and up to 600 m, 5-15 % –mainly in organic, rich muddy sediments with glauconite in some of their test. Displaced specimens also occur in the bay. This is one of the most important species of benthic foraminifera for biostratigraphic and palaeoenvironmental investigations of continental margin sediments. It was originally described by Cushman (1923), taken from a continental slope taken off the northeastern coast of the United States. Although its depth preference varies from region to region, it shows a remarkable consistency with the water depth from any area (Miller and Lohmann, 1982). Its presence can indicate high productive areas in the ocean or times of increased fertility (Lutze, 1986). On the Atlantic Iberian coast, it has been reported in Galicia (Colom, 1952), in Viana do Castelo (Fatela, 1989), in the south-southwest of Portugal (Ubaldo and Otero, 1978), and in the Algarve (Galhano, 1963). In the Mediterranean, it is abundant in the Catalan coast's muddy sediments (Mateu, 1970) and on the Motril-Nerja continental shelf (Sánchez-Ariza, 1979).

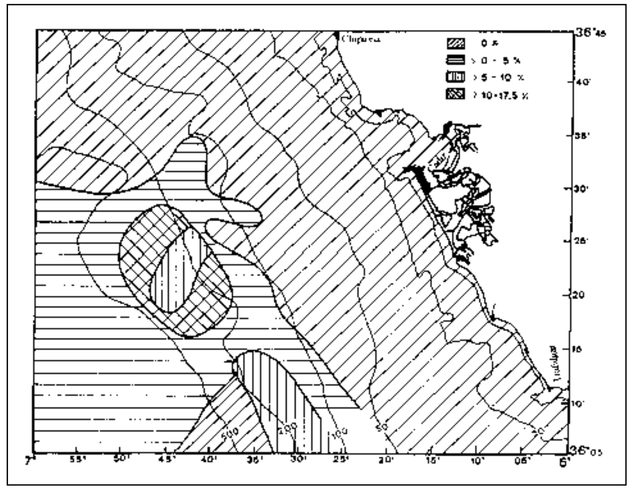

Figure 4. Distribution of *Uvigerina mediterranea*

Uvigerina mediterranea Hofker, 1932 (figure 2.2a,b,c)

Test ornamented with coarse longitudinal costae with the upper margin acute, not continuous from one chamber to the next, sutures oblique, distinct, depressed. Aperture terminal in a neck and with a coarse lib provided with an internal hemicylindrical toothplate; wall perforated with pores narrow and elongated of 1 micron, more rounded in outline and less elongated than in *U. peregrina*. Dimensions: length, 0.6-0.8 mm; width, 0.35-0.45 mm; neck, 60 microns; aperture, 60 microns. In the study zone (figure 4), it is less frequent than *U. peregrina* and is located mainly in the southwest at deeper than 100 m, with 0.1-17.5 % of the total assemblage, larger at 200-500 m, in muddy and sandy sediments. It was also correlated (coef. 0.65) with glauconite. On the Iberian coast, it has been reported on the continental shelf of Portugal (Levi *et al.,* 1995), and in the Catalan coast's muddy sediments (Mateu, 1970); it is frequent in the Alborán Sea (Mateu, 1992), and also on the Motril-Nerja continental shelf (Sanchez-Ariza, 1979).

Uvigerina auberiana d´Orbigny, 1839 (figure 2.3a,b)

Test hispid to finely spinose ornament, with the apical produced from the middle of the test, the basal shorter; the periphery is strongly lobulate, chambers globose, principally in the basal part, with the sutures oblique and distinct. In the last chamber is the aperture terminating in a large neck; wall perforated, ornamented by closely-spaced sharp spines, with complex spines in the later chambers and simple ones in the earlier chambers. Dimensions: length, 0.55 mm; width, 0.21 mm; neck, 50 microns; aperture, 50 microns. In the study zone, it was only found at three stations, in mud and fine sands. In two of them (no. 28 and 42), at depths of 600 m and 120 m, it represented 1% of the total assemblage; in the third one (no. 39), at 384 m, it represented only 0.1 %. Has been reported in closed areas on the northwest African continental shelf (Debenay and Basov, 1993) and in the Bay of Biscay, more frequently deeper than 130 m, in muddy sediments (Pujos, 1976).

Uvigerina pusilla n. sp. (figures 2.4a,b,c,d)

Derivation of the name: in an earlier work, we designated this form as *Uvigerina* sp. (Villanueva Guimerans, 1994). Here, we propose the name *pusilla* ("small", in Latin) for this species of *Uvigerina*.

Several specimens are deposited in the Spain's National Museum of Natural Sciences, in Madrid (catalogue number 33.11-1) as typical series.

Material examined: Eight dead specimens from two sites (no. 28 and 29), in the study zone.

Description: Test small, triserial, globose, circular in transversal section. A few chambers, inflated, increase in size as they are added; wall calcareous, hyaline, translucent, perforated with pores of about 0.10-0.20 microns, ornamented with 10-12 coarse longitudinal costae with the upper margin acute, best developed on the middle part of the test, interrupts in the initial part as spines. Aperture terminal rounded, on a short neck of about 20 microns with a coarse lib provided with a toothplate. Dimensions: length, 0.15 mm; width, 0.16 mm; aperture, 23 microns. Occurrence: Very rare, it was found at only two stations: one (no. 28) at a depth of 600 m in mud-fine sand sediments, representing 1.8 % of the total assemblage; and another (nº 29) at 190 m, also in mud-fine sand sediments, representing 0.1 % of the total assemblage.

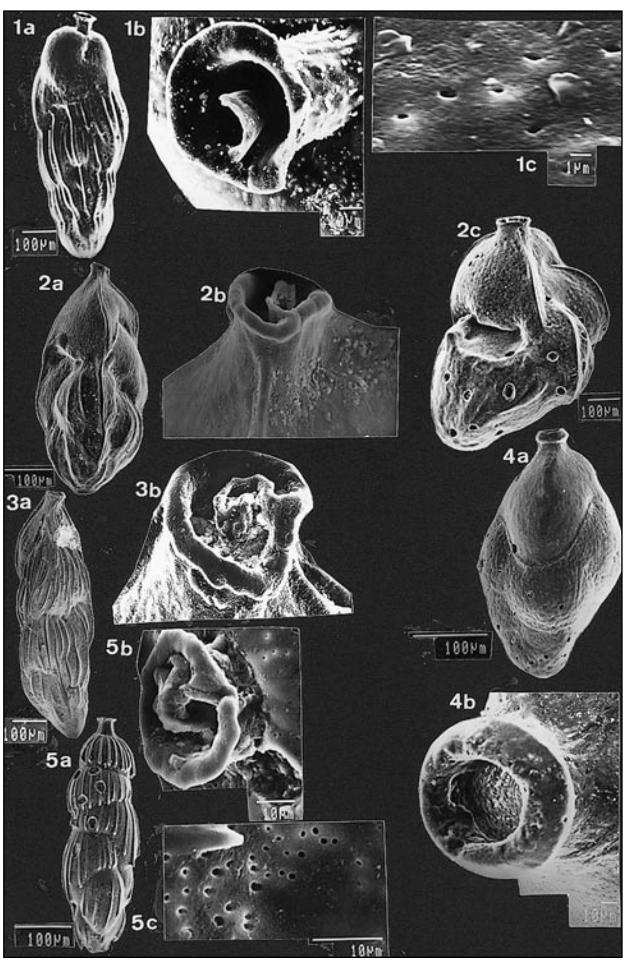

Figure 5. Uvigerinids recovered in the surface sediments. (1a,b,c): *Uvigerina elongatastriata*; (2a,b,c): *Angulogerina angulosa*; (3a,b): *Trifarina bradyi*; (4a,b): *Trifarina fornasini*; (5a,b,c): *Rectuvigerina phlegeri*

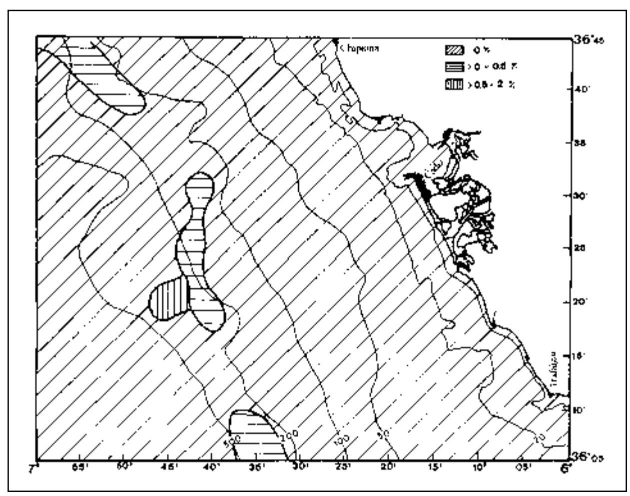

Figure 6. Distribution of *Uvigerina elongatastriata*

Uvigerina elongatastriata (Colom, 1952)
(figure 5.1a,b,c)

Test elongate, slender, periphery lobulate, chambers large, high, inflated, sutures distinct, gently curved, wall ornamented by narrow, low, spaced costae best developed in the middle part of the test, degenerating towards initial part; smooth aperture

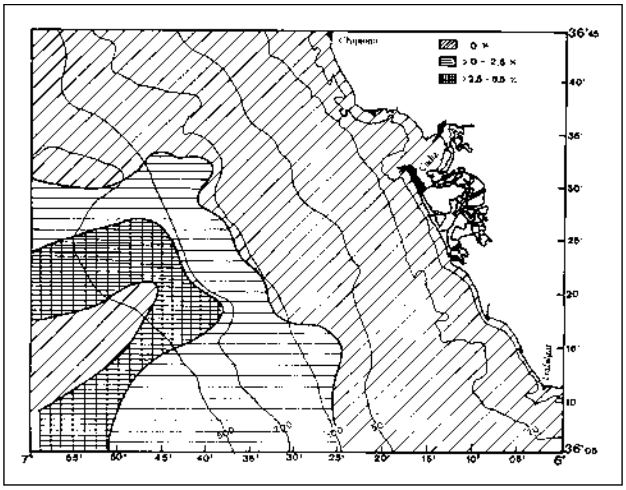

Figure 7. Distribution of *Angulogerina angulosa*

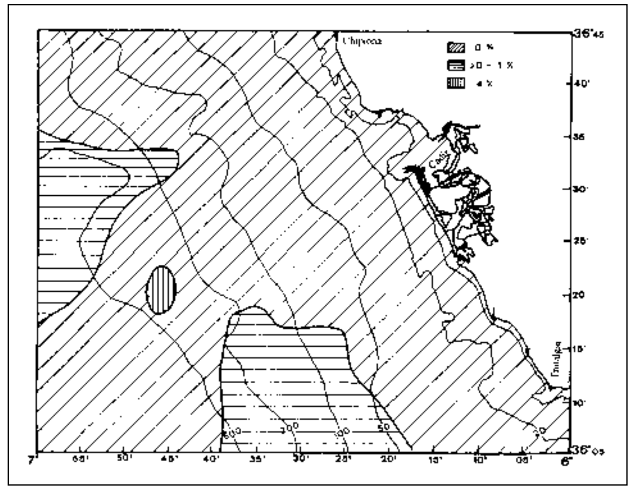

Figure 8. Distribution of *Trifarina bradyi*

terminal at end of a short neck of about 75 microns, with a phialine lip and an enrolled toothplate. Wall densely perforated with pores of about 0.75 microns. Dimensions: length, 0.85-0.90 mm; width, 0.30- 0.35 mm; aperture, 60 microns. In the study zone (figure 6), it is located in three areas down to 100 m: one in the northwest sector at a depth of 115 m in mud-fine sand sediments with 1.8 % of organic matter; second, and largest, is located between Cadiz and the Sancti Petri parallel at a depth of 200 m in muddy and fine sand sediments, representing 2 % of the total assemblage; and the third in the south at a depth of 528 m in sand sediments, representing only 0.3 % of the total assemblage. On the Iberian coast, has been reported in Galicia (Colom, 1952), Viana do Castelo (Fatela, 1989), south-southwest Portugal (Ubaldo and Otero, 1978), the Algarve (Galhano, 1963), and in the Alborán Sea in the depth-range of 100-700 m (Mateu, 1992).

Angulogerina angulosa (Williamson, 1858) (figure 5.2a,b,c)

Test elongate, triangular in transversal section, angles carinate; wall finely perforated, surface smooth or with a few widely-spaced longitudinal costae that may be continuous and emphasise the triangular section of the test; sutures slightly depressed and limbate. Aperture terminal ovate situated on a short neck, bordered by a collar-like rim and provided with a toothplate and a lip. Some anomalous specimens with a twist in the middle of the test have been found. Dimensions: length: 0.50-0.55 mm; width, 0.21 mm. In the study zone (figure 7), it is located in the medium and external continental shelf, principally downwards of 100 m with frequencies of 0.1-6.5 % of the total assemblage, correlated with water depth (coef. 0.62). On the Iberian coast it is frequently in found Cantabria (Colom, 1974), on the continental shelf of Viana do Castelo (Fatela, 1989), in the south-southwest of Portugal downwards of 115 m (Ubaldo and Otero, 1978), in the Algarve (Galhano, 1963), and in the Motril-Nerja neritic zone in the depth-range of 100-200 m (Sánchez-Ariza, 1979).

Trifarina bradyi Cushman, 1923 (figure 5.3a,b).

Test triangular, acute in horizontal section. The three external angles are carinate, wall finely perfo-

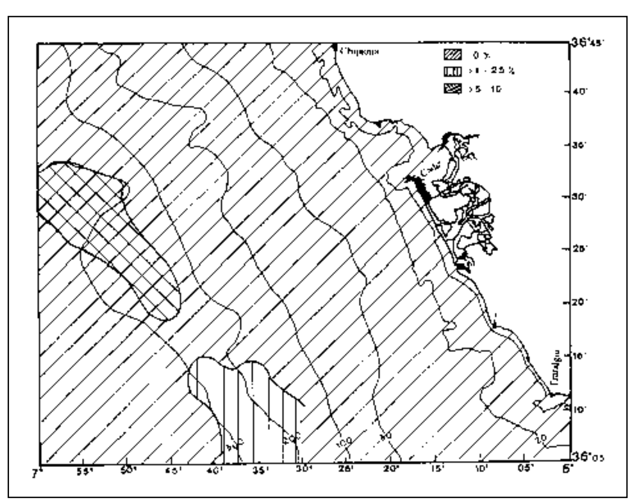

Figure 9. Distribution of *Trifarina fornasini*

rated with irregular pores and ornamented with raised elongate striae which are very conspicuous. The aperture rounded, on a short neck, and bears a toothplate. Dimensions: length, 0.80-90 mm; width, 0.20 mm; aperture, 40 microns. In the study zone (figure 8), it is located in three areas: one in the west, downwards of 127 m in sandy-mud sediments, representing 1 % of the total assemblage; another in the Sancti Petri parallel at a depth of 390 m in sand-mud sediments, representing 4 % of the total assemblage; the third, and the largest, in the south, in a depth-range of 50-500 m in sand sediments. On the Iberian coast, it has been reported on the continental shelf from Viana do Castelo (Fatela, 1989) and in the Mediterranean (Ribes and Gracia, 1991), although Sgarrella and Moncharmont-Zei (1993) propose that this species does not live in the Mediterranean, and occurs reworked from Plio-Pleistocene sediments, where it is commonly represented.

Trifarina fornasini (Selli, 1948) (figure 5.4a,b)

Test fusiform, triangular in transverse section, initial end broadly rounded; approximately 12 chambers inflated, overlapping, with weakly-developed costae on the lower half of the test, three main costae developing at the angles of the test, transversing the last two chambers, terminating at the base of the neck; sutures indistinct, depressed, curved; wall perforated with variable pores, some about 1 micron and others more elongated; surface covered with small depressions; aperture terminal, circular, at the end of a well-produced neck of about 50 microns arising from the last chamber with a thick phialine lip of about 30 microns and a toothplate. Dimensions: length, 0.90 mm; width, 0.50 mm. In the study zone (figure 9), it occurs principally in the centre, in the depth-range of 200-500 m in sandy-mud sediments, representing 10% of the total assemblage. Also, in the zone's southern sector, it represents 2.5 % of the total assemblage in sand sediments. On the Iberian coast it has been reported at a depth of 200 m in Galicia (Colom, 1952), on the continental shelf of Portugal (Levi *et al.*, 1995) and in the Alborán Sea in the depth-range of 200-300 m (Mateu, 1992).

Family Siphogenerinoididae Saidova, 1981

Rectuvigerina phlegeri Le Calvez, 1958
(figure 5.5a,b,c)

Test with the chambers obscured by ornamentation in the triserial portion, three distinct chambers in the uniserial portion, the latter comprising one-half of the test, slightly inflated; wall finely perforated with pores of 1 micron, ornamented by numerous costae interrupted in the sutures. Aperture terminal, at the end of a smooth cylindrical neck of about 20 microns, ovate, with a toothplate and phialine lip. Dimensions: length, 0.45-0.55 mm; width, 0.12-0.15 mm; aperture, 40 microns. In the study zone (figure 10), it is located in the northern sector, at depths of 20-115 m, representing 6 % of the total assemblage where fine sediments (mud) with less than 2 % sand content prevail, extending laterally from the mouth of the Guadalquivir River

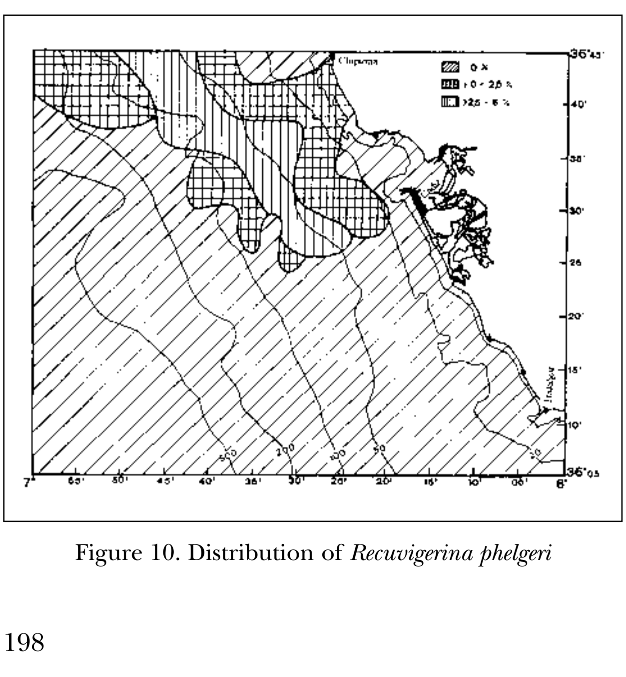

Figure 10. Distribution of *Recuvigerina phelgeri*

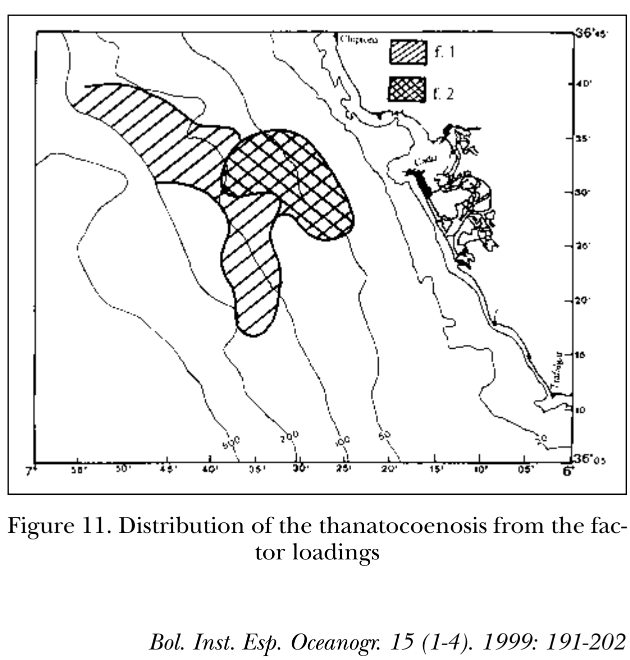

Figure 11. Distribution of the thanatocoenosis from the factor loadings

to the upper slope, whereas towards the south, they generate a progradational wedge extending over the Cadiz parallel. This species was also related with organic matter (correlation coef. 0.58). On the Iberian coast, this species has been reported on the Portuguese continental shelf (Levy *et al.,* 1995) and in the neritic Motril-Nerja zone (Sánchez-Ariza, 1979).

Data analysis

The presence of relict sediments and sediment transport events, e.g. sand and muddy movements, are factors that could render the foraminiferal assemblages in disequilibrium with the present environment and therefore of restricted use in palaeoecology. The zonation of some dead populations, i.e. multispecies assemblage in a specified area, has been referred to as thanatocoenosis; for their determination, the mathematical method described by Jöreskog, Klovan and Reyment (1976) was used. The numerical method gives a Varimax solution to Q-mode factor analysis, reducing the large matrix of foraminiferal abundance data into two smaller matrices. The matrix of Varimax factor loadings describes the importance of each factor (assemblage) at each locality; the factor score matrix reveals the relative importance of each species within each factor. The reduction of the data to this form makes it easier to determine the main faunal assemblages and facilitates mapping of foraminiferal assemblage distribution in the study zone.

Table II. Varimax rotated factor loadings with the communalities (COM) and variance

Variance	58 %	31 %	
STA.	COM	F.1	F.2
5	0.99	0.231	0.968
6	0.99	0.968	0.214
12	0.99	0.018	0.993
13	0.99	–0.201	0.968
14	0.99	0.928	0.356
15	0.99	0.983	0.068
16	0.99	0.990	0.065
17	0.99	0.976	0.073
18	0.99	0.980	0.128
19	0.99	0.015	0.993
24	0.98	0.485	0.873
31	0.97	0.960	0.203
32	0.99	0.986	0.080
35	0.99	–0.004	0.990
36	0.99	0.407	0.912
38	0.98	0.961	0.046
41	0.99	0.977	0.062
42	0.98	0.874	–0.004

Table III. Varimax rotated factor scores of two significant factors

Factor scores	F.1	F.2
U. peregrina	2.439	0.197
U. mediterranensis	–0.329	–0.344
U. auberiana	–0.166	–0.556
U. pusilla	–0.115	–0.586
U. elongatastriata	–0.475	–0.342
A. angulosa	–0.240	–0.528
T. bradyi	–0.557	–0.242
T. fornasini	–0.534	–0.337
R. phlegeri	–0.498	2.396

The Q-mode factor analysis of 27 stations determined two factor assemblages accounting for 89 % of the variance with high communalities. These are summarised here in figure 11, with the shaded areas for each assemblage representing values for factor loadings of greater than 0.75 (Williamson, Keen and Mudie, 1984) (table II), and the dominant composition of each factor score matrix summarised in table III.

Factor assemblage 1: *Uvigerina peregrina* (factor score 2.44). This is the most prevalent assemblage, accounting for 58 % of total variance. The relatively wide depth-range of this shelf assemblage (80-200 m) is a reflection of its occurrence on the medium slope, where the substrate is fine-grained, usually more than 50 % clay, and contains a rather high content of organic carbon. Factor assemblage 2: *Rectuvigerina phlegeri* (factor score 2.39), which accounts for 31 % of total variance, is restricted to the central area, between 45-100 m, also in sediments of fine grain size.

Multiple linear regression was carried out to determine the best fit between the factor loadings and certain environmental variables. The regression coefficients and statistical properties of the solutions were computed for each of six environmental variables: mud, sand, gravel, depth, carbonate, quartz.

Table IV lists the multiple correlation coefficients and some statistical properties of the multiple regression equations obtained using the linear form of the equations. It is evident that the significance of the regression coefficients varies widely among the factors. Curvilinear regression equations have also been used, containing the cross-products of factors in addition to the squares, although the results are

Table IV. Multiple linear regression coefficients

Mud: Mult. R = 0.705			Squa R = 0.497		F-value = 11.878
	RC	SERC	STDC	p-value	t-value
F1	32.45	16.81	0.35	0.064	1.94
F2	69.88	14.79	0.86	0.008	4.73
Sand: Mult.R = 0.698			Squa R = 0.488		F-value = 11.461
	RC	SERC	STAC	p-value	t-value
F1	–41.20	16.76	–0.45	0.021	–2.46
F2	–70.12	14.75	–0.88	0.007	–4.76
Gravel: Mult. R = 0.211			Squa R = 0.044		F-value = 0.56
	RC	SERC	STDC	p-value	t-value
F1	7.88	8.33	0.22	0.381	0.89
F2	0.69	7.77	0.02	0.93	0.09
Depth: Mult. R = 0.793			Squa R = 0.629		F-value = 20.361
	RC	SERC	STDC	p-value	t-value
F1	–221.00	60.89	–0.57	0.001	–3.63
F2	–341.38	53.56	–1.00	0.001	–6.37
Cal. carb: Mult. R = 0.337			Squa R = 0.113		F-value = 1.53
	RC	SERC	STDC	p-value	t-value
F1	–4.91	3.63	–0.33	0.189	–1.35
F2	–5.46	3.19	–0.41	0.100	–1.71
Quartz: Mult. R = 0.666			Squa R = 0.44		F-value = 9.594
	RC	SERC	STDC	p-value	t-value
F1	–5.97	8.09	–0.14	0.467	–0.74
F2	–27.56	7.12	–0.74	0.0007	–3.87

difficult to ecological interpret. However, the curvilinear solution produces a poor fit between data and regression lines, and it increases the Standard Error of estimates by about 55 % for environmental parameters. Therefore, a more robust linear regression model was used; an F-value testing the statistical significance of the overall regression solution was computed. Similarly, a *t*-test was used to evaluate the confidence level of the individual regression coefficients.

Multiple correlation coefficients of > 0.8 are regarded as good and interpreted as reflecting a statistically significant dependence of the distribution of particular benthic foraminiferal assemblages on the combination of specific environmental variables. Multiple R values > 0.6 are regarded as fair and interpreted as indicating a weak combined influence of specific environmental variables on the assemblage distribution, but also show that additional unmeasured variables are important. Poor values, of < 0.6, clearly indicate that the measured variables are not important.

Regressions of the two foraminiferal factor assemblages against substrate textural (mud, sand, gravel) are different. With mud, there is a multiple correlation coefficient of 0.705, which is statistically significant at the 99.0 confidence level, a good F-value. Although the standard error is relatively large for all factors, the STDC is highly significant for F2. With sand, there is a multiple correlation coefficient of 0.69, a good F-value and a highly significant STDC also for F2. With gravel, the multiple correlation coefficient is very low (0.21), the SERC is quite large, and cumulative variance is small (0.04).

In view of the importance of benthic foraminifera as paleobathymetric indicators, depth was included among the transfer functions in order to quantify objectively any relationship that might exist, and to show the expected magnitude of errors. Regressions of the two foraminiferal factors assemblages against water depth produced a multiple correlation coefficient of 0.79, which is significant at the 99.9 % confidence level, although the standard error coefficients are large for F1 and F2 (± 60 and 53 m) because the depth-ranges of some modern shelf assemblages are very large.

With respect to substrate geochemical characters, regression analysis produced a 0.66 multiple coefficient with quartz, and only 0.33 with calcium carbonate. This very low correlation can be related to the carbonate measurements, which cannot discriminate between modern biogenic carbonate and reworked carbonate from the sedimentary rocks.

DISCUSSION

Recent uvigerinids quantitatively represents about 6.6 % of total benthic foraminifera found in the study zone (Villanueva Guimerans, 1994) but although at some stations they represent the 30 %. Bandy (1960) noted the relationship between uvigerinids test morphology and bathymetry, species from the shallowest depths are mostly finely costate and slender, the next deeper forms have thicker and more heavily costate test, with increasing depth, species develop spines. In this zone in agreement with Bandy, *U. auberiana* occupies deeper positions. In the individual distribution of species a small variability reported. Some species are related with the bathymetric and sediment features such as *U. peregrina.* Their distribution is similar to the those found in other zones close Atlantic and Mediterranean and they can be located in offshore positions together with *U. elongatostriata, T. angulosa* and *T. fornasini* although in very low proportion. *R. phlegeri* is located in offshore positions. The distribution of *U. mediterranea* is similar to the distributions reported in other studies along the Atlantic close zones, deeper than Mediterranean. We found a new specie *Uvigerina pusilla* situated in medium and external continental shelf in very low concentration.

Two assemblages are characteristic for the distribution of uvigerinids in this region, a can be expected these assemblages yield a good bathymetrical separation of the sample set, from Q-mode factor analysis it can be concluded that enviromental factors directly linked with the bathymetry cause a primary separation in two different realms. The general thanatocoenoses corresponding to total uvigerinids, is located in internal and middle continental shelf between 45-200 m in sediments with high organic matter clearly related with the clay-muds from the Guadalquivir river mouth and coincides with southward-flowing North Atlantic Superficial and Central water that occupies this part of the continental shelf far-away Mediterranean influence.

Multiple regression analysis provides new insights regarding the certainty with wich environmental variables may be assigned to these organisms. The regression analysis it has enable us to say within limits of statistical certainty that the variation in F1 and F2 are moderately related to the waterdepth and the increasing amounts of organic carbon. So, is associated with muds, sands, and scarcely related to gravel and carbonate of the sediments.

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REFERENCES

Bandy, O. 1960. General correlation of foraminiferal structure with environment. In: *International Geological Congress, XXX Session* (Norden) 22: 7-9.

Buzas, M. A. 1990. Another look at confidence limits for species proportions. *J. Paleontol.* 65 (5): 842-843.

Cearreta, A. 1989. Foraminiferal assemblages in the Ría of San Vicente de la Barquera (Cantabria, Spain). *Revista Española de Micropaleontología* 30 (1): 67-80.

Colom, G. 1952. Foraminíferos de la costa de Galicia. *Boletín del Instituto Español de Oceanografía* 51: 1-44.

Colom, G. 1974. Foraminíferos ibéricos. Introducción al estudio de las especies bentónicas recientes. *Investigación Pesquera* 38 (1): 245 pp.

Cushman, J. A. 1923. The foraminifera of the Atlantic Ocean: Pt. 4. Lagenidae. *Bulletin US National Museum* 104: 228 pp.

Debenay, J. P and I. A. Basov. 1993. Distribution of recent foraminifera on the West African shelf and slope. A synthesis. *Reveu de Palébiologie* 12 (1): 265-300.

Fatela, F. 1989. Associations de foraminifères benthiques de la plataforme continentale Nord Portugaise. *Relatorio Disepla* 2/98: 60 pp.

Folk, R. 1965. *Petrology of Sedimentary Rocks.* The University of Texas. Hemphill's. Austin, (Texas), United States: 170 pp.

Galhano, M. H. 1963. Foraminiferos da costa de Portugal (Algarve). *Publicaçoes do Instituto de zoologia "Dr. Augusto Nobre"* 89: 110 pp. Faculdade de Ciencias do Porto.

Gaudette, H. E, W. R. Flight, L. Torner and D. W. Folger. 1974. An inexpensive titration method for determination of organic carbon in recent sediments. *J. Sediment. Petrol.* 44: 249-253.

Haeckel, E. 1894. *Systematische Phylogenie Entwurf eines Natürlichen Systems der Organismen auf Grund ihrer*

Stammesgeschichte. Theil 1. Systematische Phylogenie der Protisten und Pflanzen. Georg Reimer. Berlin: 150 pp.

Hofker, J. 1932. Notizen über die Foraminiferen des Golfes von Neapel, III. Die Foraminiferenfauna der Ammontatura. *Pubblicazioni Stazione Zoologica di Napoli* 12: 233-262.

Jöreskog, K., G. J. Klovan and R. Reyment. 1976. *Methods in Geomathematics, I: Geological Factors Analysis.* Elsevier. Amsterdam: 178 pp.

Le Calvez, Y. 1958. Les foraminifères de la Mer Celtique. *Reveu Traveaux Institute Pêches Maritimes* 22 (2): 147-209.

Levi, A, R. Mathieu, A. Poignant, M. Rosset, M. Ubaldo and S. Lebreiro. 1995. Foraminiféres actuels de le marge continentale portuguaise.-inventaire et distribution. *Mem. Inst. Geol. Min. Esp.* 32: 3-116.

Lobo, F. 1995. *Estructura y evolución morfosedimentaria de un sector del margen continental septentrional del golfo de Cádiz durante el Cuaternario terminal.* Doctoral thesis. Univ. Cadiz: 200 pp.

Lobo, F. J., J. Rodero, F. J. Hernández-Molina and A. Maldonado. 1997. Rasgos morfológicos de la plataforma y talud superior del Golfo de Cádiz. In: *Abstracts from the 2nd Symposium on the Iberian Atlantic Continental Margin* (September 17-20, 1997. Cádiz, Spain). F. J. Hernández-Molina *et al.* (eds.): 93-94. Univ. Cadiz.

Loeblich, A. R and H. Tappan. 1988. *Foraminiferal Genera and their Classification.* Van Nostrand Reinhold. New York: 970 pp.

Lutze, G. F. 1986. Uvigerina species of the Eastern North Atlantic. *Utrecht Micropaleontological Bulletins* 22 (35): 21-46.

Lutze, G. F. and M. Coulbourn. 1984. Recent benthic foraminifera from the continental margin of northwest Africa: community structure and distribution. *Mar. Micropaleontol.* 8: 361-401.

Mateu, G. 1970. Estudio sistemático y bioecológico de los foraminíferos vivientes de los litorales de Cataluña y Baleares. *Trabajos del Instituto Español de Oceanografía* 38: 85 pp.

Mateu, G. 1992. Los foraminiferos del Mar de Alborán. *Desplegable. Instituto Español de Oceanografía.*

Mathews, R. 1945. Rectuvigerina, a new genus of foraminifera from a restudy of Siphogenerina. *J. Paleontol.* 19: 588-606.

Mélières, F. 1974. *Recherches sur la dynamique sédimentaire du golfe du Cadiz (Espagne).* Doctoral thesis. Univ. Paris: 235 pp.

Miller, K. G. and G. Lohmann. 1982. Environmental distribution of Recent foraminifera on the northeast United States continental slope: *Geol. Soc. Am. Bull.* 93: 200-206.

Orbigny, A. d´. 1839. *Foraminiferès.* In: *Histoire physique, politique et naturalle de l´Ile de Cuba.* Ramón de la Sagra (ed.): 1-224. Bertrand. Paris.

Pascual Cuevas, A. 1984. Los foraminíferos actuales del litoral vizcaino. In: *Kobie* (Ser. Paleoantropología y C. Naturales). Revista de Ciencias. Diputación Foral de Vizcaya. 14: 341-350.

Pujos, M. 1976. Ecologie des foraminiferes benthiques et des thecamoebiens de la Gironde et du Plateu continental Sud-Gascogne. *Memoires del I´nstituit de Geologie du Bassin D´Aquitaine* 8: 274 pp.

Ribes, T. and M. Gracia. 1991. Foraminifères des herbiers de Posidonies de la Méditerranée Occidentale. *Vie Milieu* 41 (2/3): 117-126.

Saidova, Kh. M. 1981. O sovremennom sostoyanii sistemy nadvidovykh taksonov Kaynozoyskikh bentosnykh foraminifer (On a up-to-date system of supraspecific taxonomy of Cenozoic benthonic foraminifera). Moscow: *Inst. Okeanologii P. P. Shirshova, Akademiya Nauk SSSR.*

Sánchez-Ariza, M. C. 1979. *Estudio sistemático-ecológico de los foraminíferos recientes de la zona litoral Motril-Nerja.* Doctoral thesis 211. Univer. Granada Press, Granada (Spain): 212 pp.

Schnitker, D. 1979. The deep waters of the North Atlantic during the past 24 000 years and the re-initiation of the western Boundary under-current. *Mar. Micropaleontol.* 4: 265-280.

Schönfeld, J. 1997. The impact of the Mediterranean Outflow Water on benthic foraminiferal assemblages and surface sediments at the southern Portuguese continental margin. *Mar. Micropaleontol.* 29: 211-236.

Seiglie, G. A. 1968. Foraminiferal assemblages as indicators of high organic carbon content in sediments and polluted waters. *Bull. Am. Assoc. Petrol. Geologists* 52: 2231-2241.

Selli, R. 1948. Atti della Societá Italiana di Scienze Naturali 87: 40.

Sgarrella, F. and M. Moncharmont-Zei. 1993. Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Bolletino de la Societá Paleontologica Italiana.* 32 (2): 145-264.

Ubaldo, M. L. and M. Otero. 1978. Foraminíferos da costa su-sudoeste de Portugal. *Serie Geologica. Lisboa.* 2: 77-130.

Villanueva Guimerans, P. 1994. *Implicaciones oceanográficas de los foraminíferos bentónicos recientes en la Bahía y plataforma continental gaditana. Taxonomía y asociaciones.* Doctoral thesis. Univ. Cadiz: 395 pp.

Williamson, W. C. 1858. On the Recent Foraminifera of Great Britain. *Ray. Society Publication. London* XX: 107 pp.

Williamson, M. A., C. Keen and P. J. Mudie. 1984. Foraminiferal distribution on the continental margin off Nova Scotia. *Mar. Micropaleontol.* 9: 219-239.

Zwaan, G. J. van der. 1982. Paleoecology of Late Miocene Mediterranean Foraminifera Foraminifera. *Utrecht Micropaleontology Bulletin* 25: 1-202.

Zwaan, G. J. van der, F. Jorissen, P. J. Verhallen and C. von Daniels. 1986. Uvigerina from the Eastern Atlantic, North Sea basin, Paratethys and Mediterranean. *Utrecht Micropaleontology Bulletin* 35: 7-20.